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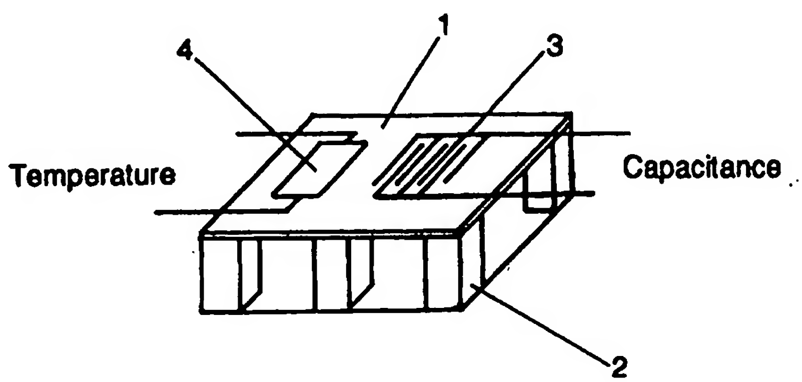
(54) Title: A DEW POINT SENSOR



(57) Abstract

A dew point sensor comprises a miniature capacitor (3) comprising insulated electrodes on the surface of a chip (1) on which water condenses between the capacitor plates, temperature sensor (4) adjacent to the capacitor (3), on the chip (1), a peltier cooler (2) arranged to cool the capacitor (3), and a microcontroller. The microcontroller is arranged to measure variations in capacitance from condensation and evaporation of water on and from the capacitor plates, to measure the temperature of the capacitor (3), and to control the peltier cooler (2) to maintain the temperature of the capacitor plates to around the measured dew point. In the preferred form the microcontroller is arranged to control the peltier cooler (2) to cool the capacitor (3) to below the dew point temperature, to allow the temperature of the capacitor (3) to increase until water is left predominantly at the edges of the capacitor fingers and to then determine the dew point by allowing the temperature of the capacitor (3) to increase towards the measured dew point at which the rates of condensation onto and evaporation from the fingers of the capacitor (3) are substantially equal.

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A DEW POINT SENSOR

FIELD OF INVENTION

The invention comprises a dew point sensor and method.

BACKGROUND

The water vapour content of a gas may be measured by several techniques. The most basic method which is readily accessible uses the temperature at which dew condenses out onto a chilled surface. Relative humidity may then be calculated from this temperature and the temperature of the environment.

Dew point sensors have most commonly been implemented by the use of a light beam whose specular reflection from a mirror surface tends to scatter when dew forms, but electrical methods have also been used, such as the change in capacitance of a structure when water (which has a high dielectric constant) condenses on the surface. The advantage of capacitive detection is a system with fewer parts, in which in principle, the water load can be measured; optical methods merely detect a state of surface roughness which may or may not correspond to a particular water load. Because only surface roughness is required, optical methods are extremely sensitive to the onset of dew; however a difficulty then arises because it is well known that condensation appears at temperatures above the true dew point if the mirror surface

is contaminated. Frequent cleaning is required to guard against this occurring if good accuracy is required.

SUMMARY OF INVENTION

The present invention comprises a miniature dew point sensor which senses the dew load capacitively operating under microprocessor control.

In broad terms the invention comprises a dew point sensor to detect the dew point of a vapour-containing gas, such as air containing water vapour, comprising:

a miniature capacitor or micro-capacitor comprising insulated electrodes on the surface of a chip, the size and surface relief of which control the disposition of the condensation which may form from the surrounding vapour when the chip is cooled,

a temperature sensor adjacent to the capacitor on the chip,

a peltier cooler arranged to cool the capacitor, and

a microcontroller arranged to measure variations in capacitance from condensation and evaporation of water on and from the capacitor plates, to measure the temperature of the capacitor, and to control the peltier cooler to maintain the temperature of the capacitor plates to around the dew point in conditions of static and rapidly changing humidity.

Preferably the microcontroller is arranged to control the peltier cooler to maintain the capacitor at a dew loading at which the effect of contamination on the sensor has a minimal effect on the dew point and at which the rates of condensation onto and evaporation from the sensor are substantially equal, thereby indicating the measured dew point.

Preferably the microcontroller is arranged to control the peltier cooler to approach the dew point temperature from below the dew point temperature.

Preferably the microcontroller is arranged to monitor the level of contamination on the sensor by reference to the gradient of the relationship between temperature and capacitance about the dew point temperature.

Preferably the chip is a silicon chip.

DESCRIPTION OF DRAWINGS

The invention will be further described with reference to the drawings which show by way of example a preferred form dew point sensor of the invention. In the drawings:

Figure 1 schematically shows the sensor unit of the preferred form dew point sensor, showing a silicon slice on which the capacitor plates and temperature measurement device are formed and a peltier cooler attached thereto,

Figure 2 is a cross-section through the silicon slice and capacitor plates of Figure 1,

Figure 3 shows the relationship between temperature and capacitance for sensors of the invention,

Figure 4 shows capacitance versus temperature for clean and contaminated sensors, and

Figure 5 shows the control loops of the microcontroller of the preferred form dew point sensor.

DETAILED DESCRIPTION OF PREFERRED FORM

Figure 1 shows the sensing element of the preferred form dew point sensor. This comprises a silicon chip 1 attached to a peltier cooler 2. The chip 1 is made by silicon integrated circuit fabrication methods and contains a miniature capacitor or microcapacitor which in the preferred form is an interdigitated capacitor 3, and a temperature sensor such as a solid state temperature sensor in close proximity. The thermal coupling between the two is high as a result of the high thermal conductivity of silicon. In the preferred form the interdigitated capacitor is made of two comb-like polycrystalline silicon (polysilicon) shapes, the fingers of which are interleaved as shown. The resulting capacitor fingers and the spaces between them are very small for example of the order of 5 microns.

A cross-section through the chip 1 is shown in Figure 2. The polysilicon layer forming the capacitor 3 is isolated from the silicon substrate 1 by a layer of oxide 5 and protected from the atmosphere by first oxidising the top layer of polysilicon 3 to silicon dioxide, then overcoating the entire structure with a thin layer of silicon nitride 6 produced by low pressure chemical vapour deposition. The capacitance of such structures can vary as humidity is increased from low to high values. Overcoats such as silicon dioxide can absorb water vapour and show a capacitance rise before 100% humidity is reached but silicon nitride is a good barrier material and resists hydration; it shows very little increase in capacitance at high humidities due to water vapour absorption. It is therefore preferred to overcoat the capacitor 3 with the silicon nitride layer or a layer of another material which resists hydration so that capacitance changes before condensation forms are minimal. A further feature of the device is the very smooth surface achieved by the construction methods described above. Both the feature size and the smooth surface of the sensor impact on the way it is operated because of the effect they have on dew formation.

Figure 3 shows the capacitance measured as the sensor is cooled below the dew point by the peltier cooler 2. If the sensor is clean, some degree of supercooling below the dew point can be required to initiate condensation and cause the capacitance to rise - point A in Figure 3. Condensation is nucleated at the sharp height discontinuities at the edges of the polysilicon fingers of the capacitor 3 and can be transported along them to build up at the corners of the electrode combs or other discontinuities. With continued cooling below the dew point isolated drops of water may appear on the fingers 3 and between them. Water load grows progressively and the spaces between the fingers will eventually flood, but the capacitance

increases slowly in this regime - part B in Figure 3. The dew point is found by controlling the peltier cooler to slowly increase temperature - part C in Figure 3 - until water is left predominantly in the crevices at the edges of the fingers. At this point, the capacitance is extremely sensitive to dew load - point D in Figure 3 - which flashes off with small increases in temperature. The electronic control algorithm holds the temperature at the point D, which is closely the dew point. The same behaviour is seen on a soiled sensor, but transport along the edges of the fingers is decreased.

On starting the instrument, the microcontroller begins by initiating a learning cycle which explores the hysteresis curve of Figure 3. The desired water configuration in which the deposit is not allowed time to flow along to the ends of the fingers is then achieved by allowing capacitance to build to a desired value by holding the sensor briefly at the predetermined point C, then moving immediately along the heating curve to D.

The smallness of the device results in a fast response, and allows a high degree of control of the dew load. It has been found that even with a freshly cleaned sensor, the equilibrium capacitance-temperature curve in the vicinity of point D has a finite slope. It is not vertical. The equilibrium capacitance-temperature curve is represented by line A in Figure 4. On a real surface this may be expected because it can never be perfectly clean at the molecular level. It is known that the incorporation of solute into a solution causes a raising of the dew point (the Raoult effect) which is concentration dependent. Dissolved contamination therefore will produce a raised dew point on all practical surfaces, but the point of equilibrium will approach the dew point as the water load builds and the solution concentration falls. On a heavily

contaminated surface, it is well known that moisture begins to form significantly above the true dew point, as illustrated in line B. It has been found in practice that the line B steepens in slope as the temperature is lowered. As long as the capacitance set point (D in Figure 3) is high enough, the difference between lines A and B decreases and the dew point error is quite small.

The difference in Figure 4 between a clean and dirty sensor allows for an automatic reporting of the state of contamination of the sensor by examining the slope of the capacitance temperature equilibrium curve. To do this, the microcontroller adjusts the set-point D of capacitance in Figure 3 to a new value to establish a new equilibrium temperature. For clean surfaces, it has been found that changing the dew load by an amount corresponding to a capacitance change of 0.8 to 1.8 pF requires a temperature change of only about 0.02 degrees. To ensure that a reliable estimate of the slope has been obtained, several iterations of the procedure are performed. Such performance checks may be done during the course of normal operation, or during command calibration sequences.

The difference between the operating point D and the dry capacitance has been found to be approximately 1pF, which requires accurate measurement of capacitance. The small size of the device and close thermal coupling of the temperature sensor 4 enable control algorithms to be devised which allow fast tracking of swings of humidity. However, the non-linear form of the capacitance-temperature transfer function around the dew point, and the fact that the exchange time constant for water evaporation and condensation is strongly dependent on the vapour pressure at the dew point presents complexities in devising a control algorithm.

Figure 5 outlines schematically one approach which has been used, which incorporates adaptive elements to match the sensor performance to the prevailing conditions.

Temperature is controlled by powering the peltier unit by loop 1 which operates under proportional-integral conditions, with modifications to control the slew rate to values appropriate for the mode of operation, for example learn cycle, normal operation, cleanliness report mode. Loop 2 exercises control of the capacitance also via the peltier cooler, but operates slower than loop 1.

Dew point is defined as occurring when the rate of evaporation equals the rate of condensation, which implies that the rate of change of capacitance is zero, or $\dot{C}=0$. Referring to Figure 3 this condition is chosen to apply at the point D, where $\dot{C}=\dot{C}_{set}$.

These two conditions, $\dot{C}=0$ and $\dot{C}=\dot{C}_{set}$, are implemented by loop 2A using proportional-differential control, modified by a "drift" term. The derivative control is applied not only to produce the $\dot{C}=0$ condition, but also to cause the operating point to drift controllably to the set point. This mimics the effect of integral control in producing zero error, while ensuring that the associated driving temperatures do not vary significantly from the dew point as could occur if conventional integral control were implemented. Such control also overrides the environmental-dependent integral implicit in the dew formation process. The derivative term is adaptive; it becomes active during times of change but decays away automatically if conditions are stable, thereby minimising noise under the latter conditions.

If the humidity suddenly changes, it is possible that the dew load may produce a capacitance near the extremes of the transfer function. A second over-ride loop 2B is brought into play under these conditions. This exercises high gain proportional control to return the capacitance to the control range of loop 2A, in a manner which accounts for the delay in response due to the time constant of water formation and evaporation. Ongoing temperature corrections are made, not based on the difference between the measured capacitance and the set-point, but on whether or not the measured capacitance, given its time constant, is tending in the expected way to the set point as a result of the previous temperature correction. Allowance can be made for changes in this time constant with prevailing conditions. Since the temperature algorithm operates much faster than the time required for significant capacitance changes to occur, the effect is to account for the integrated effect of previous temperature adjustments in the approach to the capacitance set point.

The over-ride loop 2B becomes inactive automatically when the value of capacitance is close to the set-point D, but not necessarily at D. Note that the new dew point temperature in practice will be quite close to the original value. Over a period of time, the equilibrium is drifted so that the capacitance moves back towards the desired set point. During the time the second loop 2B is in control, the system can deviate from equilibrium, and the temperature of the surface not represent the dew point. However, from the control algorithm it is possible to estimate the size of the temperature error, and use this to correct the value of dew temperature which is output. Using this two-level control the device can respond to step changes of humidity of 50% at room temperature in less than a second.

It has been found that ice or frost does not begin to form on the sensor until dew point temperatures below -25 degrees are reached. Above this temperature, the condensate is supercooled water. Below -30 degrees, frost forms directly. Ice crystals or frost give a capacitance-temperature response which differs from water because they lack the ability of the latter to flow along or exist within the surface features of the capacitor. Their presence may therefore be distinguished from dew. The sensor may be used at temperatures where frost and ice crystals form directly, for example in measuring dryness of gases. A preferred method of operation in this situation is to cool the sensor until ice forms, as seen by a rise in capacitance, and then to slowly raise the temperature to establish the point of sublimation.

In situations where ice may form from supercooled dew, a mode of operation can be implemented which is a combination of the water control mode and the ice mode.

The forgoing describes the invention including a preferred form thereof. Alterations and modifications as will be obvious to those skilled in the art are intended to be incorporated within the scope hereof.

CLAIMS

1. A dew point sensor to detect the dew point of a vapour-containing gas comprising:

a miniature capacitor or micro-capacitor comprising insulated electrodes on the surface of a chip, the size and surface relief of which control the disposition of the condensation which may form from the surrounding vapour when the chip is cooled,

a temperature sensor adjacent to the capacitor on the chip,

a peltier cooler arranged to cool the capacitor, and

a microcontroller arranged to measure variations in capacitance from condensation and evaporation of water on and from the capacitor plates, to measure the temperature of the capacitor, and to control the peltier cooler to maintain the temperature of the capacitor plates to around the dew point in conditions of static and changing humidity.

2. A dew point sensor according to claim 1, wherein the microcontroller is arranged to indicate the measured dew point by controlling the peltier cooler to maintain the capacitor at a dew loading at which the rates of condensation onto and evaporation from the sensor are substantially equal.

3. A dew point sensor according to claim 2, wherein the microcontroller is arranged to control the peltier cooler to approach the measured dew point temperature from below the dew point temperature.

4. A dew point sensor according to claim 3, wherein the miniature capacitor or microcapacitor comprises at least two capacitor plates formed on a substrate material and interleaved with each other.

5. A dew point sensor according to claim 4, wherein the capacitor plates comprise at least two comb-like rows of spaced fingers.

6. A dew point sensor according to claim 4 or claim 5, wherein the microcontroller is arranged to control the peltier cooler to cool the capacitor to below the dew point temperature, to allow the temperature of the capacitor to increase until water is left predominantly at the edges of the capacitor plates and to then determine the dew point by allowing the temperature of the capacitor to increase towards the measured dew point at which the rates of condensation onto and evaporation from between the capacitor plates are substantially equal.

7. A dew point sensor according to anyone of claims 1 to 6, wherein the microcontroller is arranged to control the peltier cooler to maintain the capacitor at a dew loading at which the effect of contamination on the sensor has a minimal effect on the dew point.

8. A dew point sensor according to claim 7, wherein the microcontroller is arranged to monitor the level of contamination on the sensor by reference to the gradient of the relationship between temperature and capacitance about the dew point temperature.

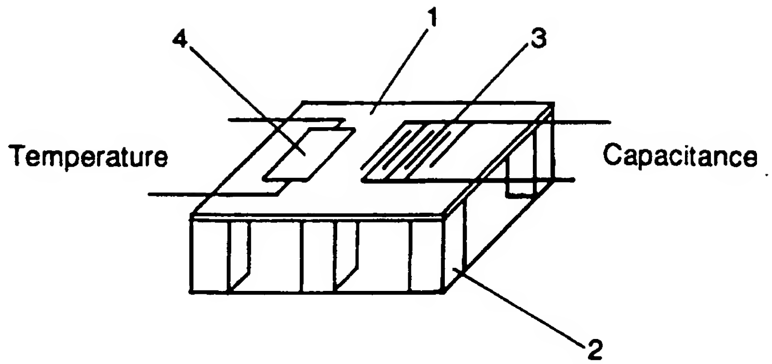

FIG 1

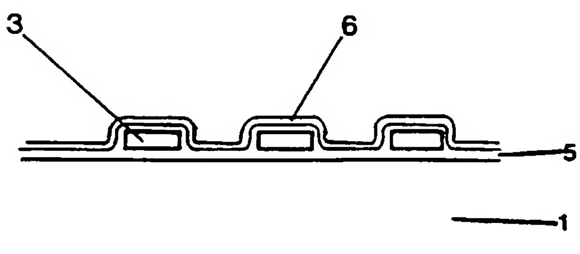

FIG 2

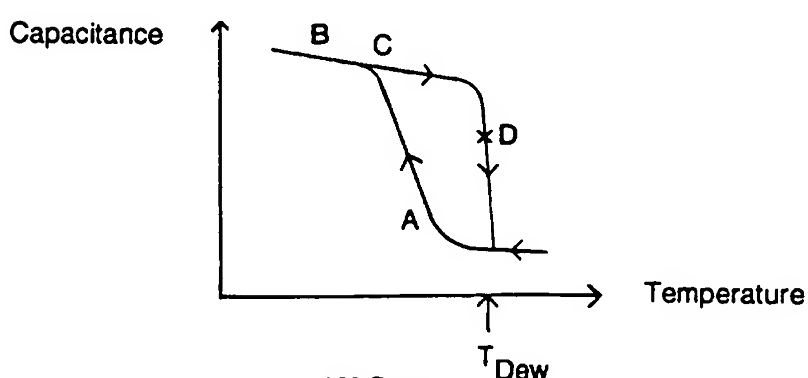

FIG 3

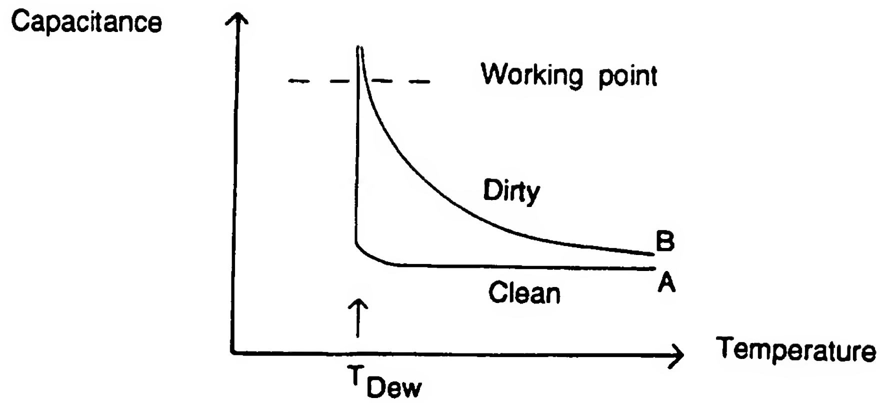
Capacitance
Working point
Dirty
B
A
Clean
Temperature
T_{Dew}

FIG 4

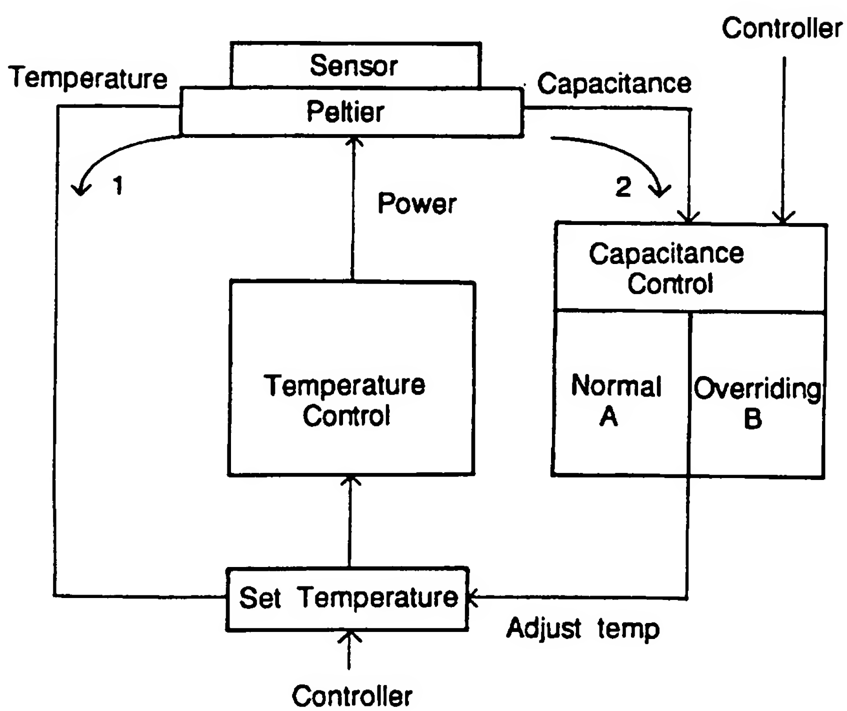
Controller
Temperature
Sensor
Capacitance
Peltier
1
Power
2
Capacitance Control
Temperature Control
Normal A
Overriding B
Set Temperature
Adjust temp
Controller

FIG 5

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/NZ 95/00074

A. CLASSIFICATION OF SUBJECT MATTER

Int Cl[6]: G01N 25/66 27/22

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC G01N 25/66 27/22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	GB 2205957 A (ENDRESS U. GMBH U CO) 21 August 1988 page 3 line 35 - page 5 line 34, Figs 1,2	1-8
Y	WO 83/03139 A (COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION) 15 September 1983 page 5 line 1 - page 7 line 34, Fig 1	1-8
Y	EP 122945 A (LICENCIA TALALMANYOKAT ERTEKESITO VALLALAT) 31 October 1984 page 2 lines 18-34	1-8

[X] Further documents are listed in the continuation of Box C

[X] See patent family annex

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Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 160884 A (JOH VAILLANT GMBH U. CO) 13 November 1985 page 7 line 4 - page 10 line 25, Fig 3	1-8

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No.
PCT/NZ 95/00074

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Patent Document Cited in Search Report		Patent Family Member					
GB	2205957	DE	3720189	FR	2616912	JP	5012661
		SE	469492	US	4948263		
WO	8303139	IT	1170318	AU	13305/83	EP	103587
EP	122945	NONE					
EP	160884	AT	56084				
							END OF ANNEX